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Jennifer D. Ahearn
Jennifer Ahearn

PATENT
Atty. Docket No. 35236-00001

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:

DANIEL LOPEZ et al.

Serial No.: 09/249,728

Filed: February 13, 1999

For: RETICLE DEFECT DETECTION USING SIMULATION

Group Art Unit: 2623

Examiner: M. Dastouri

Honorable Assistant Commissioner for Patents
Washington, D.C. 20231

TRANSMITTAL OF APPEAL BRIEF
(PATENT APPLICATION - 37 C.F.R. § 1.192)

Sir:

Transmitted herewith, in triplicate, is the Appeal Brief in the above-referenced patent application, with respect to the Notice of Appeal received by the U.S. Patent and Trademark Office on July 31, 2002.

U.S. Serial No. 09/249,728

This Appeal Brief is being submitted on behalf of Assignee, KLA-Tencor Corporation, a corporation other than a small entity.

Pursuant to 37 C.F.R. § 1.17(f) enclosed please find a check in the amount of $320.00 to cover the filing fee for the Appeal Brief. If any additional fees are due for the filing or the Appeal Brief, the Commissioner is authorized to charge them to Deposit Account No. 13-3735.

Respectfully submitted,

MITCHELL, SILBERBERG & KNUPP LLP

Dated: September 27, 2002

By Joseph G. Swan
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PATENT
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APPELLANTS' BRIEF
ON APPEAL TO THE BOARD OF PATENT APPEALS AND INTERFERENCES

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

Appellants in the above-captioned patent application appeal the final rejection of claims 1 to 22, as set forth in the Office Action dated March 25, 2002, pursuant to the Notice of Appeal which was filed (together with a Petition for One-Month Extension of Time) on July 25, 2002 and received by the USPTO on July 31, 2002.

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I. REAL PARTY IN INTEREST

The real party in interest in this application is KLA-Tencor Corporation, pursuant to an assignment which was recorded at reel 9937, frame 0765 on May 6, 1999.

II. RELATED APPEALS AND INTERFERENCES

Appellants are not aware of any related appeals or interferences.

III. STATUS OF CLAIMS

Claims 1 to 22 have been finally rejected and are the subject matter of this Appeal. In accordance with 37 C.F.R. § 1.192(c)(9), a copy of the claims involved in this appeal is included in Appendix A attached hereto.

IV. STATUS OF THE AMENDMENTS

No amendments have been filed subsequent to the final rejection.

V. SUMMARY OF THE INVENTION

Conventionally, integrated circuits (ICs) are manufactured by a photolithographic process, in which a light beam is projected through a photomask, or reticle, in order to produce a desired light pattern on an underlying IC semiconductor wafer. The light reaching the IC wafer interacts with resist materials on the wafer's surface to define a corresponding pattern of shapes and channels on the wafer. After additional processing, those shapes and channels form the electronic circuits of the IC. Thus, reticles play a key role in mapping the circuit patterns onto an IC wafer substrate. Similar photolithography also is used to transfer wire routing patterns onto metal layers that subsequently are deposited on top of the semiconductor substrate, thereby forming the necessary interconnections between the semiconductor components.

In order to produce functioning integrated circuits at a high yield rate, the reticles need to be free of defects, or at least free of defects that would adversely affect the photolithographic process or the resulting IC chips. While automated techniques conventionally have been employed to identify defects in a manufactured reticle, typically each such defect still must be classified to determine whether it will have a significant adverse effect on the IC chips that the reticle will be used to manufacture. Conventionally, such classification generally has required inspection by a human operator. Such conventional inspection may involve studying the defective portion of the mask and then making a judgment based on the operator's experience and/or may involve placing the reticle into an optical emulation device (such as a simulation microscope) in order to observe the patterns produced when light is projected through the reticle. Each such inspection technique often is difficult and time-consuming, particularly given the fact that it is not uncommon for the defect detection software to identify 800 or more defects on a single reticle, with the operator having to classify each one individually.

The present invention addresses this problem by detecting reticle defects using digital image data that correspond to an image of the reticle, processing such digital image data to identify defects (e.g., using a conventional technique) and then processing at least a portion of such digital image data to simulate a response that would be produced if the reticle were utilized in a photolithographic system. Such a simulation, for example, include only aerial image simulation (i.e., calculating the light intensities that would result on the surface of the IC) or aerial image simulation in combination with resist simulation processing (i.e., calculating the actual surface patterns that would result by taking into account the resist's response to the light). See Specification page 9, lines 10 to 14. A variety of photolithography simulation programs are available, although their use conventionally has been limited mainly to reticle design, in which it is desired to know how a proposed reticle design will perform. See

Specification page 9, line 15 to page 10, line 26. Accordingly, in the preferred embodiment of the invention, such off-the-shelf software is modified to permit analysis of scanned-in image data for an actual reticle, as opposed to merely simulating an idealized design representation of a reticle. See Specification page 10, line 26 to page 11, line 21.

In short, according to the present invention, once the digital image data for the reticle have been obtained (e.g., by scanning the reticle), both defect detection and defect classification can be performed using the same digital image data. As a result, the benefits of a hardware emulation often can be obtained without the necessity of obtaining an optical emulator or the necessity of performing an additional manual step of placing the subject reticle into such an emulator. In addition, because the present invention uses the same data for defect detection and simulation, it is a relatively simple matter to quickly and automatically present the simulation areas of interest to an operator, in contrast to the difficulty in locating defect areas when a separate optical emulator is used. Thus, the approach of the present invention is believed to allow faster and more efficient defect detection and classification than conventional techniques would permit, thereby reducing the costs of reticle fabrication.

VI. ISSUES PRESENTED ON APPEAL

The issues are: (i) whether claims 1 to 4, 6 to 11, 13 to 17, 19, 21 and 22 are properly rejected under 35 U.S.C. § 103(a) over U.S. Patent 5,619,429 (Aloni) in view of U.S. Patent 6,016,357 (Neary); whether claims 5 and 12 are properly rejected under § 103(a) over Aloni in view of Neary and U.S. Patent 5,965,306 (Mansfield); and whether claims 18 and 20 are properly rejected under § 103(a) over Aloni in view of Neary and U.S. Patent 6,171,731 (Medvedeva).

VII. GROUPING OF THE CLAIMS

In the Office Action, the Examiner grouped the pending claims in a particular manner. However, for purposes of the present appeal, Appellants believe that the claims are more appropriately grouped as follows:

GROUP 1: Claims 1, 3 to 5, 8, 17, 18 and 21
GROUP 2: Claims 9, 11 to 14, 16, 19, 20 and 22
GROUP 3: Claims 2 and 10
GROUP 4: Claim 6
GROUP 5: Claim 7
GROUP 6: Claim 15

It is therefore Appellants' intent that, solely for purposes of the present Appeal and for refuting the specific arguments set forth by the Examiner, the claims in each of the foregoing groups will stand or fall together, except that whenever any claim in one group depends (whether directly or indirectly) from a claim that ultimately is determined to be allowable, such dependent claim also should be allowed for at least the same reasons.

VIII. ARGUMENT

DISCUSSION OF ISSUES ON APPEAL

The requirements for establishing a *prima facie* case of obviousness for a § 103 rejection have been stated as follows:

> "a proper analysis under § 103 requires, inter alia, consideration of two factors: (1) whether the prior art would have suggested to those of

> ordinary skill in the art that they should make the claimed composition or device, or carry out the claimed process; and (2) whether the prior art would also have revealed that in so making or carrying out, those of ordinary skill would have a reasonable expectation of success. [citing In re Dow Chemical Co., 837 F.2d 469, 473, 5 U.S.P.Q.2D 1529, 1531 (Fed. Cir. 1988).] Both the suggestion and the reasonable expectation of success must be found in the prior art, not in the applicant's disclosure."
>
> In re Vaeck, 947 F.2d 488, 493 (Fed. Cir. 1991).

Summarizing the requirements for a § 103 rejection, M.P.E.P. § 2142 provides that, in order to establish a *prima facie* case of obviousness, the Examiner must cite prior art references that teach or suggest all of the claim limitations, and if more than one such reference is required to disclose all such limitations, there must be some suggestion or motivation, either in the prior art references themselves or in the knowledge generally available to one of ordinary skill in the art, to combine the reference teachings.

Thus, the applied art must clearly disclose or suggest all of the features recited in each rejected claim. As shown below, the foregoing tests for establishing obviousness under § 103 have not been met for any of the following groups of claims.

Group 1 Claims

Claims 1, 3 to 5, 8, 17, 18 and 21 are directed to detecting defects in a reticle used in integrated circuit chip fabrication by obtaining digital image data corresponding to an image of a reticle. The digital image data are processed according to predetermined criteria to identify defects, and a response that would be produced if the reticle were utilized in a photolithographic system is simulated by processing the digital image data corresponding to the reticle.

The foregoing combination of features is not disclosed or suggested by the applied art. In particular, the applied art does not disclose or suggest at least the

feature of processing digital image data corresponding to a reticle both to identify defects and to simulate a response that would be produced if the reticle were to be utilized in a photolithographic system.

In this regard, Aloni discusses the conventional technique of processing digital image data corresponding to a reticle for the purpose of identifying defects. However, as acknowledged by the Examiner, Aloni does not disclose or suggest the feature of also using such digital image data to simulate a response that would be produced if the reticle were to be utilized in a photolithographic system.

In order to make up for this deficiency, the Examiner cites Neary as showing such simulation. However, Appellants have reviewed Neary in detail and are unable to find this feature of the present invention either disclosed or suggested anywhere in Neary. The specific portions of Neary cited by the Examiner are addressed as follows:

* *Figure 2, defect 24*: This drawing element clearly shows a defect in a portion of a reticle, but by itself indicates itself nothing at all about performing a simulation as in the present invention.

* *Figure 10*: This drawing illustrates Neary's technique, but also is not seen to disclose or to suggest simulation by processing digital image data for a reticle. To the contrary, as described at column 6, lines 35 to 40, Neary utilizes an "aerial image measurement tool" to <u>emulate</u> the exposure tool upon which the mask ultimately is to be used. Column 3, lines 55 to 58, of Neary further clarifies that the "aerial image measurement tool" measures intensity of an aerial image by illuminating the reticle (or mask) with the desired light source (preferably using the Microlithography Simulation Microscope 100 AIMS). IBM Journal of Research and Development, Optical Lithography, Volume 41, Numbers 1/2, 1997, discussing the Microlithography

Simulation Microscope 100 AIMS, is attached hereto as Appendix B and clearly shows that this referenced Microscope is an optical device.

Thus, Neary uses an optical system to emulate the aerial image produced by a mask. This is significantly different than processing digital image data corresponding to a reticle in order to simulate a response that would be produced if the reticle (or a portion thereof) were to be utilized in a photolithographic system, as recited in the present claims. It is noted that Neary does discuss utilizing a simulator to predict an <u>ideal</u> aerial image (column 6, lines 43 to 46); however, *first*, it is not clear whether such a "simulator" utilizes digital image data at all and, *second*, in any event, such simulation is performed only for predicting an <u>ideal</u> aerial image and not for an actual defective reticle, as in the present invention.

* *Figure 16*: This drawing illustrates an overlay of an idealized portion of a mask and the same portion of a defective mask. However, nothing in Figure 16 indicates anything at all about performing a simulation as recited in the present claims.

* *Column 6, line 25 through column 7, line 4*: As discussed above, this section of Neary describes use of an optical tool to emulate an exposure tool, thereby providing an aerial image for a mask, and then comparison of this aerial image to some unspecified simulation of an <u>ideal</u> aerial image. Nothing in this portion of Neary says anything at all about processing digital image data for a <u>reticle</u> to simulate use of the reticle in a photolithographic system, as recited in the present claims.

Similar comments to the above were set forth in the Response filed by Appellants on October 17, 2001 in this case. In response, the Examiner asserted that the Microlithography Simulation Microscope 100 AIMS described in Neary's column 3 processes digital image data corresponding to a reticle in order to simulate a response

that would be produced if the reticle were to be utilized in a photolithographic system. However, nothing in Neary indicates that this is the case. To the contrary, and as noted above, Column 3, lines 55 to 58, of Neary clarifies that his "aerial image measurement tool" measures intensity of an aerial image by illuminating the reticle (or mask) with the desired light source. Similarly, at column 3, lines 61 to 62, Neary states that "The device includes apertures that can emulate commercially available printing tools." Column 6, lines 36 to 39, of Neary states that the emulation is performed "by stepping the mask image transmission through multiple focus values . . ." These quotations and others strongly indicate that Neary's Microlithography Simulation Microscope is in fact an optical emulation device, rather than a simulation device that processes digital image data corresponding to a reticle. Similarly, the paper attached as Appendix B hereto also clearly shows that the referenced Microlithography Simulation Microscope is an optical emulation device.

As a result, neither Aloni nor Neary discloses or suggests the feature of processing digital image data corresponding to a reticle both to identify defects and to simulate a response that would be produced if the reticle were to be utilized in a photolithographic system. Lacking this feature of the invention, no permissible combination of the applied art could have rendered the present claims obvious.

Accordingly, claims 1, 3 to 5, 8, 17, 18 and 21 are believed to be allowable over the applied art.

<u>Group 2 Claims</u>

Claims 9, 11 to 14, 16, 19, 20 and 22 are directed to detecting defects in a reticle used in integrated circuit chip fabrication by obtaining digital image data corresponding to an image of a reticle and processing the digital image data according to predetermined criteria to identify defects. A window is then specified around one of the identified defects and a response that would be produced if the specified window

were to be utilized in a photolithographic system is simulated by processing digital image data corresponding to the specified window.

The foregoing combination of features is not disclosed or suggested by the applied art. In particular, the applied art does not disclose or suggest at least the features of specifying a window around a defect identified in digital image data corresponding to a reticle and then simulating a response that would be produced if the specified window were to be utilized in a photolithographic system, by processing digital image data corresponding to the window.

In the most recent Office Action, the Examiner primarily relies on "arguments analogous to those" used to reject the Group 1 claims. Thus, to the extent the Examiner relies on such grounds, the comments set forth above in connection with the Group 1 claims are incorporated in this section as though set forth herein in full. The remainder of the comments in this section will focus on certain differences between the Group 1 claims and the present claims.

Specifically, the present claims also include the feature of simulating a response that would be produced if a window that is specified around an identified defect in digital image data were to be utilized in a photolithographic system. With regard to this feature of the invention, the Examiner merely points to the two-dimensional moving window memory array 228 in Figure 12 and to column 25, line 63 to column 26, line 22 of Aloni. While that portion of Aloni does describe specifying a window around an identified defect for the purpose of postprocessing, nothing in Aloni, Neary or any combination of the two suggests simulating any response produced by such a window, much less a response as recited in the present claims. In fact, the Examiner has not even alleged that it does. Similarly, Neary appears to say nothing at all about using windows, and the Examiner has not even alleged that it does.

As a result, claims 9, 11 to 14, 16, 19, 20 and 22 are believed to be allowable over the applied art.

Group 3 Claims

Claims 2 and 10 depend from independent claims 1 and 9, respectively, and recite the further limitation that the digital image data used for the simulation are obtained by scanning the reticle. This feature of the invention is not disclosed or suggested by the applied art.

In this regard, the Examiner cites column 9, lines 40 to 42, of Aloni. That portion of Aloni does discuss scanning an object to be inspected. However, there is no indication in Aloni that the resulting image data are to be used for any form of simulation, much less as recited in the present claims. Neary does not appear to even mention scanning a reticle to obtain image data, and the Examiner has not alleged that it does. Thus, neither applied reference shows this feature of the invention. In addition, it is noted that Neary also does not suggest simulating a reticle by using image data of the type produced by Aloni's scanning operation. Accordingly, there would have been no motivation to combine Neary with Aloni in any manner that would have provided the present feature of the invention.

For these additional reasons, claims 2 and 10 are believed to be allowable over the applied art.

Group 4 Claim

Claim 6 depends from independent claim 1 and recites the further limitation that the digital image data used for the simulation are in raster format. This feature of the invention is not disclosed or suggested by the applied art.

In this regard, the Examiner cites column 9, lines 40 to 42, of Aloni and asserts that a digital image inherently is in raster format. Appellants acknowledge that the cited portion of Aloni discusses scanning an object to be inspected, and Appellants agree that scanned image data typically are initially in raster format. However, there is no indication in Aloni that the resulting raster image data are to be used for any form of simulation, much less as recited in the present claims, and the Examiner has not even

alleged that it does. Also, Neary does not appear to even mention using reticle image data in raster format, and the Examiner has not alleged that it does. Accordingly, there would have been no motivation to combine Neary with Aloni in any manner that would have provided the above-referenced feature of the invention.

For these additional reasons, claim 6 is believed to be allowable over the applied art.

<u>Group 5 Claim</u>

Claim 7 depends from independent claim 1 and recites the further limitation that a format of the digital image data is modified prior to performing the simulation. This feature of the invention is not disclosed or suggested by the applied art.

In this regard, the Examiner has cited Figure 3 and column 4, lines 28 to 37, of Neary as showing this feature. However, Figure 3 merely shows, and the cited textual portion merely describes, the physical operation of cutting away or trimming the ragged portion of a defect and then observing the resulting light pattern prior to repairing the defect. This optional trimming step is a physical operation performed on the mask under observation in Neary's system and has nothing at all to do with modifying the format of digital image data that represent a reticle prior to performing a simulation using such digital image data.

For these additional reasons, claim 7 is believed to be allowable over the applied art.

<u>Group 6 Claim</u>

Claim 15 depends from independent claim 9 and recites the further limitation that the digital image data processed to produce the simulation are grayscale data. This feature of the invention is not disclosed or suggested by applied art.

In this regard, the Examiner cites column 9, lines 40 to 42, of Aloni. That portion of Aloni does discuss scanning an object to be inspected into a grayscale

representation. However, there is no indication in Aloni that the resulting image data are to be used for any form of simulation, much less as recited in the present claims. Neary does not suggest simulating a reticle using image data of the type produced by Aloni's scanning operation. Accordingly, there would have been no motivation to combine Neary with Aloni in any manner that would have provided the present feature of the invention.

For these additional reasons, claim 7 is believed to be allowable over the applied art.

CONCLUDING REMARKS

As Appellants have shown above, for a number of different reasons, nothing in the applied art discloses or suggests the invention recited by the claims on appeal. Appellants therefore respectfully submit that the claimed invention is patentably distinct over the applied art.

In view of the foregoing remarks, Appellants respectfully request that the rejection of claims 1 to 22 be reversed and a Notice of Allowance issued.

Respectfully submitted,

MITCHELL, SILBERBERG & KNUPP LLP

Dated: September 27, 2002

By Joseph Swan

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APPENDIX A

Claims on Appeal

1. A method for detecting defects in a reticle used in integrated circuit chip fabrication, said method comprising:

(a) obtaining digital image data corresponding to an image of a reticle;

(b) processing the digital image data according to predetermined criteria to identify defects; and

(c) simulating a response that would be produced if the reticle were to be utilized in a photolithographic system, by processing the digital image data corresponding to the reticle.

2. A method according to Claim 1, wherein the digital image data are obtained by scanning the reticle.

3. A method according to Claim 1, wherein the defects are identified in step (b) by comparing the digital image data to reference digital image data.

4. A method according to Claim 1, wherein step (c) simulates an aerial image which would be produced by the reticle.

5. A method according to Claim 1, further comprising a step of categorizing defects based on simulation results produced in step (c).

6. A method according to Claim 1, wherein the digital image data are in raster format.

7. A method according to Claim 1, further comprising a step of modifying a format of the digital image data prior to performing step (c).

8. A method according to Claim 1, further comprising a step of providing a reference simulation for comparison to a simulation produced in step (c).

9. A method for detecting defects in a reticle used in integrated circuit chip fabrication, said method comprising:

(a) obtaining digital image data corresponding to an image of a reticle;

(b) processing the digital image data according to predetermined criteria to identify defects;

(c) specifying a window around one of the defects identified in step (b); and

(d) simulating a response that would be produced if the window specified in step (c) were to be utilized in a photolithographic system, by processing digital image data corresponding to the window specified in step (c).

10. A method according to Claim 9, wherein the digital image data are obtained by scanning the reticle.

11. A method according to Claim 9, wherein step (d) simulates an aerial image which would be produced by the window.

12. A method according to Claim 9, further comprising a step of categorizing defects based on simulation results produced in step (d).

13. A method according to Claim 9, further comprising a step of simulating a window of corresponding reference image data for comparison to simulation results produced in step (d).

14. A method according to Claim 9, wherein the window is 64 x 64 pixels.

15. A method according to Claim 9, wherein the digital image data processed in step (d) are grayscale data.

16. A method according to Claim 9, wherein the defects are identified in step (b) by comparing the digital image data to reference digital image data.

17. A computer-readable medium having encoded thereon computer-executable process steps, said process steps for detecting defects in a reticle used in integrated circuit chip fabrication, wherein said process steps comprise steps to:

(a) obtain digital image data corresponding to an image of a reticle;

(b) process the digital image data according to predetermined criteria to identify defects; and

(c) simulate a response that would be produced if the reticle were to be utilized in a photolithographic system, by processing the digital image data corresponding to the reticle.

18. A computer-readable medium according to Claim 17, wherein said computer readable medium comprises at least one of a magnetic diskette, magnetic tape, a CD-ROM, a random access memory chip, and a read-only computer memory chip.

19. A computer-readable medium having encoded thereon computer-executable process steps, said process steps for detecting defects in a reticle used in integrated circuit chip fabrication, said process steps comprising steps to:

(a) obtain digital image data corresponding to an image of a reticle;

(b) process the digital image data according to predetermined criteria to identify defects;

(c) specify a window around one of the defects identified in step (b); and

(d) simulate a response that would be produced if the window specified in step (c) were to be utilized in a photolithographic system, by processing digital image data corresponding to the window specified in step (c).

20. A computer-readable medium according to Claim 19, wherein said computer readable medium comprises at least one of a magnetic diskette, magnetic tape, a CD-ROM, a random access memory chip, and a read-only computer memory chip.

21. An apparatus for detecting defects in a reticle used in integrated circuit chip fabrication, said apparatus comprising:

a processor for executing stored program instruction steps; and

a memory connected to the processor for storing the program instruction steps,

wherein the program instruction steps include steps to:

(a) obtain digital image data corresponding to an image of a reticle;

(b) process the digital image data according to predetermined criteria to identify defects; and

(c) simulate a response that would be produced if the reticle were to be utilized in a photolithographic system, by processing the digital image data corresponding to the reticle.

22. An apparatus for detecting defects in a reticle used in integrated circuit chip fabrication, said apparatus comprising:

a processor for executing stored program instruction steps; and

a memory connected to the processor for storing the program instruction steps,

wherein the program instruction steps include steps to:

(a) obtain digital image data corresponding to an image of a reticle;

(b) process the digital image data according to predetermined criteria to identify defects;

(c) specify a window around one of the defects identified in step (b); and

(d) simulate a response that would be produced if the window specified in step (c) were to be utilized in a photolithographic system, by processing digital image data corresponding to the window specified in step (c).

Serial No.: 09/249,728

APPENDIX B

IBM Journal of Research and Development
Optical Lithography, Volume 41, Numbers 1/2, 1997

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IBM Journal of Research and Development

Volume 41, Numbers 1/2, 1997
Optical lithography

Table of contents: HTML ASCII

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Development and application of a new tool for lithographic mask evaluation, the stepper equivalent Aerial Image Measurement System, AIMS

by R. A. Budd, D. B. Dove, J. L. Staples, R. M. Martino, R. A. Ferguson, and J. T. Weed

This paper describes the development of a new tool for evaluating lithographic masks, its software, and its application to the development of advanced mask designs, including phase-shifted features. This mask-imaging system, known as the stepper equivalent Aerial Image Measurement System (AIMS*), provides a means for rapid evaluation of masks. The key feature of AIMS is that the mask is imaged under conditions that emulate the image produced by a given lithographic exposure tool onto a resist layer. In the AIMS microscope, the image obtained is enlarged so as to permit quantitative measurement with a low-noise CCD camera. A quantitative record of selected features of the mask is useful in predicting the printability window for given mask and stepper combinations. Details of the optical system and extensive software capability are given, and examples are presented of feature printability of phase-shifted features, optical proximity, and other effects. Applications include the prediction of key critical mask dimensions as a function of exposure and depth of focus and the rapid checking of the effectiveness of repair actions prior to validation by resist runs. The AIMS microscope system is available as the Carl Zeiss MSM100 Microlithography Simulation Microscope and is now in use in a number of companies as a new tool for mask fabrication and development.

Introduction

The continuing drive to extend the capability of optical lithography to increasingly smaller dimensions has led to the development of exposure tools of higher numerical aperture (NA) and shorter wavelengths, to the exploration of new mask technologies such as phase-shift methods [1,2], and to the refinement of mask layouts to include optical proximity effects.

Mask design has become increasingly complex, since it is difficult to predict the printing characteristics of a mask exposure tool combination solely from knowledge of the layout geometry. Extensive use of computer programs such as Splat or Image is commonly the primary means for understanding the through-focus behavior for mask features such as parallel lines with phase shift or vias with attenuating phase shift. After mask design and fabrication, the printing characteristics of the mask are studied by printing a matrix covering a range of exposures and focus settings. These experimental test chips are then parted, and key features are measured using a scanning electron microscope; this is a time-consuming procedure.

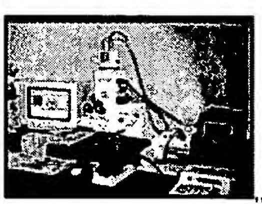
The Aerial Image Measurement System (AIMS*)[1] was designed to provide a means for rapidly evaluating the exposure and depth-of-focus characteristics of real masks, including chrome, proximity-corrected, phase-shifted, or attenuating phase types, prior to resist validation. This device has been found to provide a new means for examining masks capable of providing useful information in a very short time before resist experiments are undertaken [3-5].

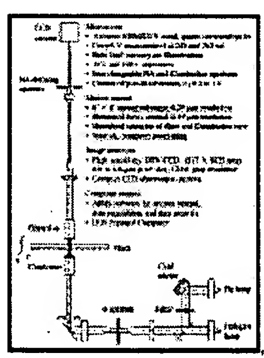
A UV microscope was set up in which the NA of the imaging lens was adjusted so that the image produced possesses the same resolution characteristics as that of a particular stepper.

In order to emulate effects introduced by phase shifts or optical proximity, the masks are imaged at the wavelength of use (in the present case, 365 or 248 nm). An aperture was also placed in the illumination system so that coherence could be matched and explored. In addition, multiple off-axis apertures may be used to emulate off-axis illumination such as the Canon or Nikon approach. Initial experiments were carried out in which images were compared with extensive computer simulation and with resist features for a wide variety of cases. Good agreement was found between computer simulations and AIMS images obtained for test masks under a variety of conditions. In most cases it is sufficient to predict resist behavior via a high-contrast resist model. If desired, the image data may be used as a starting point for more extensive resist calculations.

Tool development and description

Early in the development of phase-shift masks at IBM, it became clear that a method of evaluating photomask performance more rapidly than time-consuming traditional means was urgently needed. A novel laboratory setup consisting of an industrial microscope modified to control illumination σ and objective lens NA was developed to emulate the imaging characteristics of an optical stepper. From the prototype, a commercial version was co-developed with Carl Zeiss Inc. and is available as the Microlithography Simulation Microscope, MSM100 (**Figure 1**). **Figure 2** shows a schematic layout of the MSM100 tool, which is based upon a deep-UV Axiotron microscope with several important differences that allow it to emulate optical steppers. Illumination is provided by a 100-W mercury arc lamp for I-line and deep-UV (365-and 248-nm) imaging, and by a halogen lamp for visual inspection and alignment. Light from the mercury lamp is prefiltered by a cold mirror, dumping excess IR radiation into a heat sink. A narrow-bandpass filter, mounted in an automatic filter changer, establishes the center wavelength (either 365 or 248 nm) with a bandwidth of typically <10 nm FWHM. The coherence or σ of the light incident upon the photomask is controlled by an aperture positioned at a point in the base of the microscope conjugate with the objective lens pupil. This σ aperture is mounted on a slider so that various sizes may be easily selected. New optical steppers from Canon or Nikon incorporate off-axis illumination sources to improve the resolution of the stepper. These illumination sources can also be studied with the AIMS microscope by inserting the appropriately shaped aperture into the σ slider. The condenser lens focuses the illumination onto a small (submillimeter) region of the photomask. This focusing differs from that of the optical stepper, in which a large area of the mask is illuminated. Five- or six-inch photomasks may be mounted on the 8 × 8-in. motorized stage. The stage is driven vertically to collect through-focus image data. One feature of the optical system is that a large focus motion of the microscope stage corresponds to a small amount of defocus within a lithographic exposure tool; thus, defocus conditions of only a fraction of a micron may be readily simulated. The imaging system NA is controlled by an aperture mounted on a slider in the upper column of the microscope. A two-stage optical system magnifies the mask image onto a Photometrics high-sensitivity UV CCD camera, which is liquid-cooled to -40°C to ensure low noise. The 1317 × 1035-pixel-array camera has an intensity resolution of 12 bits per pixel, sufficient for quantitative image data analysis. The performance of the AIMS microscope was verified for a series of σs and NAs by comparing image data with computer simulations and resist features; good correlation was shown [3].


,,,,Figure 1


,,,,Figure 2

Software package
An extensive software package was developed to provide a user-friendly graphical interface for the AIMS setup, control, data collection, and analysis. The program was written in Microsoft Visual C++** for the Microsoft Windows® operating system. The C++ class structure provides a modular environment for easy program extendibility.

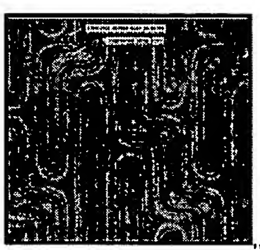
The program software communicates with the AIMS tool through a serial communication port to the Zeiss MCU26 microscope stage, as well as through a custom ISA bus adapter to the Photometrics camera. The serial link controls the stage position, filter changer, and lamp selector. The AIMS program, communicating with the Photometrics camera adapter, quickly transfers image data from the camera to the computer memory.

The program provides easy management of a variety of tool control functions. The camera type, speed, and resolution, the MCU26 controller parameters, and the objective lens calibration file are initialized on start-up of the program to their last saved values. All of these parameters can be changed through program menus. An interactive graphical display shows the current position of the lamp selector, the filter changer, the lens turret, and the dark- and bright-field sliders. Additional routines provide for aperture alignment, mask focus, and mask positioning.

After loading a mask onto the stage, it is often desirable to determine the correlation between mask and stage coordinates. By using common alignment marks on the mask and following a three-point alignment process, mask rotation and magnification correction factors are determined. This permits quick and accurate mask positioning to desired mask or stage coordinates. A KLA inspection machine is commonly used to check a mask for defects. This inspection results in a report or list of potential defect sites. The list is easily imported into the AIMS program and used to move the mask swiftly from site to site to evaluate the printability of these defects.

To assist the data acquisition process, several image-capture parameters and routines are available: a quick image preview and alignment mode, image size, and exposure settings. Since features on a photomask are usually 1-3 µm in size (for 5× masks), it is not necessary to capture and store the entire 100 × 128-µm region of the mask that is optically imaged onto the camera. A subfield is often specified defining the region of interest. Once set up, single-focus images and/or through-focus images may be acquired and stored for further analysis. For documentation purposes, a data header is attached to each image file to record the mask designation, measurement conditions, and user comments.

Image analysis
A variety of image analysis and data display routines are built into the AIMS software program. Upon capture, the image is displayed on the screen using either a linear gray-scale, pseudo-color, or threshold-highlight palette, thus providing a qualitative picture of the data (**Figure 3**). A contour plot may then be calculated for a series of intensity threshold values (**Figure 4**). The contour plot provides a quick approximation of how the image would print in a high-contrast resist at specified threshold values.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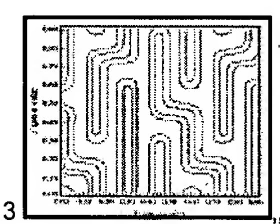
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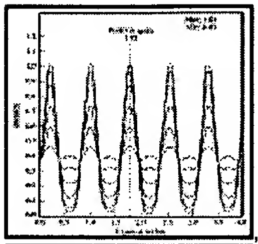
To provide quantitative views of the data, plots showing profile, linewidth versus threshold, linewidth versus defocus, and exposure defocus are available. Profile plots (**Figure 5**) may be calculated for a vertical or horizontal slice of the image. The mouse may be used to select a

single bright or dark feature in the profile plot for further analysis. The linewidth versus defocus plot (**Figure 6**) is determined by calculating the width of the selected feature for specified intensity thresholds over the range of focus. This analysis method provides a quick means of determining expected resist feature linewidth variations versus defocus. Finally, the exposure defocus plot (**Figure 7**) is calculated by further specifying the permitted tolerance in feature size and plotting the limits in exposure over the range of focus.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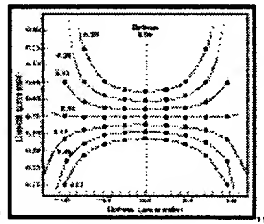
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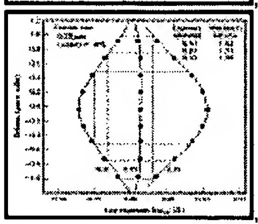
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These analysis methods are extremely valuable in determining the printability of mask defects. While conventional mask inspection tools may determine defect size, other factors (such as edge wall shape and defect phase) are not easily measured. The AIMS tool measures the aerial imaging performance of the mask directly, combining effects of mask amplitude, phase, and surface topography, a result not obtained by other inspection methods. Further analysis of the image may be performed by importing the data file into an advanced workstation program, for example to perform photoresist development simulations.

Photolithography involves many factors such as the reticle, exposure system, and photoresist process which influence the final result obtained on the substrate. These factors typically have a complex relationship to the final results and require numerous experiments for optimization. The typical time required to perform an experiment capable of assessing the performance of a lithography system can range from several days to several months, depending on the complexity of the experiment. The AIMS technology of rapid measurement and image analysis offers a means of emulating the lithography system by significantly reducing the time and cost required to evaluate lithographic performance.

Applications of AIMS

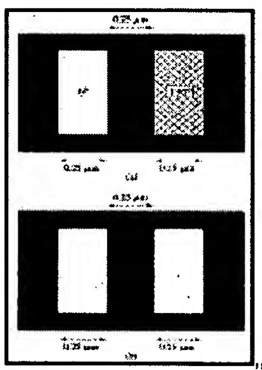
While each component of the lithography system is important to the overall performance, the mask or reticle technology is rapidly becoming a critical and complex element of the process. The masks/reticles are either binary intensity masks (BIMs), in which the circuit pattern is defined on a quartz substrate by an opaque material (Cr/CrO), or phase-shift masks (PSMs), in which mask materials and/or topography are utilized to delineate phase-shifted regions which modify the wavefronts incident on the wafer through destructive interference. This modification can result in improved resolution, exposure latitude, and/or depth of focus relative to BIMs. Unfortunately, improved performance is obtained at the expense of increased complexity in the reticle fabrication process. In addition to transmission, phase must also be controlled.

While a variety of PSM techniques exist (attenuated, alternating, rim, and outrigger), the attenuated and alternating techniques are the most generally studied. In the attenuated PSM, the dark areas of the mask typically transmit the exposure energy (5-10% relative intensity) with a 180° phase relative to the clear areas [6]. The alternating PSM method of Levenson et al. [1] utilizes alternating light regions to transmit exposure energy (100% relative intensity) with a 180° phase relative to a neighboring light region [7]. Additive or removal techniques may be

used to create alternating phase structure (among which etched quartz technology is the most prevalent).

Inaccurate control of fabrication parameters for a PSM can have a detrimental impact on lithographic performance. There may be deviations from theory, such as transmission reduction through a phase-shifted opening which is dependent on etch roughness as well as electromagnetic scattering phenomena from the sidewalls of the etched opening. In addition to transmission, phase errors will exist if the correct material depth relative to the refractive index is not obtained. This error may be produced by etch endpoint inaccuracy during quartz removal in a subtractive quartz process, and film property imperfections may be produced by variations in an attenuated film deposition process.

Fabrication processes have been developed to address these deviations from theory in order to optimize lithographic performance. A post-etch treatment (also referred to as an etch-back process), in which an isotropic wet etch moves the etched-quartz sidewalls beneath the bordering chrome film, compensates for the strong impact of electromagnetic scattering [8]. AIMS measurements were used to fine-tune this process on a special feature in a 0.25-μm DRAM cell design [5], as shown in **Figure 8**. The aerial image measurement in **Figure 9** demonstrates the effect of the etch-back process on the amount of optical scattering in the phase-shifted opening. The optical scattering produces an intensity transmission error, as seen on the no-etch case, by its reduced peak intensity. The peak intensity of the phase-shifted opening clearly increased relative to the non-phase-shifted opening as the wet-etch depth increased. Optimum lithographic performance was identified with an approximate etch-back of 1200 Å [5].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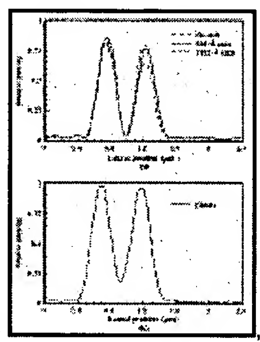
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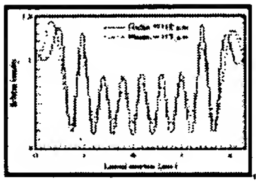
Phase optimization for alternating and attenuated PSM processes was also established by applying the AIMS. Alternating PSM processes have an inherent asymmetry when the phase is not ideal. This asymmetry provides a method of extraction which relies on a comparison of the size of adjacent features through focus. This difference in size of adjacent openings of opposite phase (ΔCD) can be expressed in terms of a phase error,

$$\Delta \mathrm{CD} = A(\Delta\theta \cdot \mathit{defocus}) + B(1 - \sqrt{(1 - \Delta T)}),$$

where $\Delta\theta$ is the phase error and ΔT is the intensity transmission error. The phase error defines the slope of the ΔCD curve. The *A* and *B* parameters in Equation (1) depend on the design of the alternating pattern and exposure system NA, wavelength, and partial coherence.

AIMS measurements were used to characterize an actual alternating PSM process. With the AIMS tool configured with $\lambda = 248$ nm, NA = 0.5, and $\sigma = 0.6$, aerial image measurements were taken through focus for a 0.20-μm alternating line/space grating, as shown in **Figure 10**. The difference in intensity peak width for lines of opposite phase was determined as a function of focus and plotted in **Figure 11** at multiple thresholds. A value of phase was then extracted using Equation (1). The phase was found to be 5° from optimum, requiring an etch depth correction.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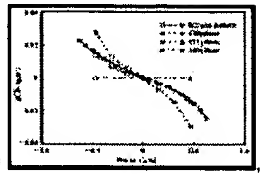
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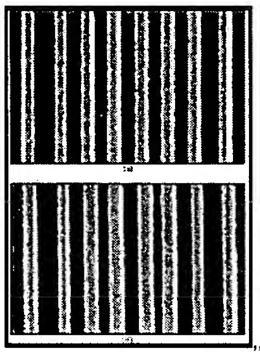
Effects of the phase error observed in the AIMS measurements were also confirmed using stepper exposures on the Micrascan® II from SVG Lithography Systems, Inc. (SVGL). **Figures 12(a)** and **12(b)** respectively show the 0.20-μm pattern in 0.6 μm of APEX-E resist at 0 and 0.25-μm defocus. The defocused condition clearly shows resist openings of differing width, in contrast to the 0.0 defocus condition, in which all resist openings are of uniform width. This is consistent with the aerial image, in which neighboring intensity peaks vary in size for the defocused condition.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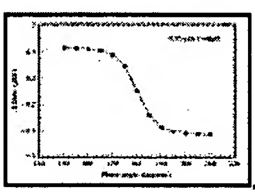
The phase of an attenuating PSM is particularly difficult to ascertain, since it depends on the real and imaginary parts of the refractive index of the phase-shifting material as well as the depth into the mask substrate. The AIMS tool, however, provides a means of measuring the phase through the comparison of aerial image focus characteristics of a contact and lines [9,10]. Small contact holes receive the greatest improvement of all feature types from attenuating phase shifting, and are therefore the most sensitive to any phase error. The action of a phase error is to shift the optimal focal plane in either a positive or a negative direction. Other structures such as the line/space grating are not as sensitive to phase, producing a significantly smaller change to the feature's focus characteristics. By quantifying the difference in focus at which a maximum size is achieved for a contact and nested lines, the AIMS tool can be used to determine attenuated PSM phase errors. Fabrication parameters can then be optimized. **Figure 13** shows the difference in focus for a 0.35-μm contact compared to a 0.35-μm line/space pattern as a function of phase error.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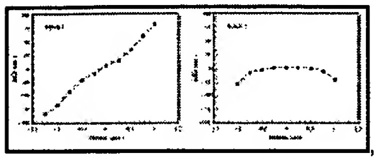
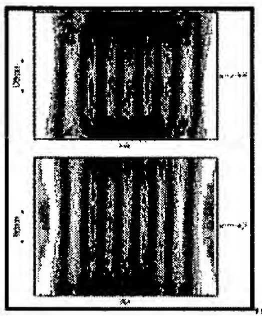
The ability of the AIMS tool to identify fabrication errors rapidly makes it ideal for mask qualification, in which good reticles can be separated from bad. This is demonstrated with the DRAM cell feature in Figure 8. Two masks were fabricated with this pattern using the same manufacturing process. **Figure 14** shows the **Δ**CD versus defocus characteristics of the two reticles. A significantly larger phase error exists for the first reticle, as exhibited by the large slope of the **Δ**CD curve versus the near-zero slope of the second reticle. This conclusion was further supported with exposure-defocus analysis, which showed a 62% improvement in DOF for a 15% variation in exposure for the second reticle compared to the first. In addition, the improved performance was confirmed using stepper exposures on the SVGL Micrascan II.


,,,,Figure 14

Lithographic performance optimization is required once fabrication parameters are established and mask qualification is complete. The AIMS tool provides a rapid means of optimization for stepper parameters such as numerical aperture and partial coherence [11]. This is demonstrated for the 0.20-μm alternating line/space grating shown in Figure 10. Aerial image measurements were taken through focus with the AIMS configured at λ = 248 nm, NA = 0.5, and σ = 0.6 and 0.3. **Figure 15** shows the intensity distributions, with the 0.3 partial coherence clearly having improved image contrast and through-focus performance. Quantification of the improvement is established through an exposure-defocus analysis.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Summary

The Aerial Image Measurement System has been introduced for evaluating lithographic masks; its application to the development of advanced mask designs has been described, and details of its optical system and its software capability have been given. It has been found that analysis of the stepper equivalent image produced by the AIMS tool provides a new capability for rapid evaluation of the printing properties of chrome and phase-shifted masks prior to undertaking extensive resist-validation exposures and SEM feature size measurements. Examples have been presented demonstrating its application to the optimization of the mask fabrication process, measurement of mask phase error, characterization of feature printability, and optimization of mask photolithographic performance.

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*AIMS is a trademark of International Business Machines Corporation.

**Visual C++ is a trademark, and Microsoft Windows is a registered trademark, of Microsoft Corporation.

Micrascan is a registered trademark of SVG Lithography Systems, Inc.

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[1] Patent applied for in 1994.

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